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PIBEP-68-018.1

AD 680308

Research and Development Technical Report
ECOM-0222-1

AN EXPERIMENTAL STUDY OF RADIO WAVE PROPAGATION IN SIMULATED FORESTS AND OTHER DISSIPATIVE ENVIRONMENTS

by

Theodor Tamir

SEMIANNUAL REPORT

September 1968

This research was sponsored by:

Advanced Research Projects Agency
ARPA Order 371

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UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

Contract DAAB 07-68-C-0222

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TECHNICAL REPORT ECOM-0222-1

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September 1968

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SEMIANNUAL REPORT

15 February - 15 August 1968

Report No. 1

CONTRACT DAAB 07-68-C-0222

This research was sponsored by:

Advanced Research Projects Agency
ARPA Order 371

Prepared for:

U. S. Army Electronics Command
Fort Monmouth, New Jersey 07703

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ACKNOWLEDGEMENT

This work was technically and contractually monitored by the U. S. Army Electronics Command, Fort Monmouth, New Jersey under Contract No. DAAB 07-68-C-0222.

SUMMARY

The general features of a set-up that is intended to serve as the laboratory model for a forest environment are discussed and the considerations concerning the frequency of operation, the basic measurements to be undertaken and the appropriate characteristic parameters are described. The dielectric material that would simulate a vegetative medium was the subject of extensive experimentation which represents the major effort during the past interval. Satisfactory dielectric media were produced by doping a foaming material with carbon powder or with absorbent fibers. Their properties and electrical characteristics were measured and are reported herein.

PURPOSE

The scope of this investigation is to simulate a forest environment in a small-scale laboratory model for the study of electromagnetic wave propagation under conditions which include dissipation losses. In particular, the presence of lateral waves is to be verified for the purpose of utilizing their properties in reducing communication losses.

I. OUTLINE OF RESEARCH PROGRAM

Theoretical considerations of radio wave propagation in forest environments have shown[1] that many communication aspects in the frequency range of 1 - 200 MHz may be examined in terms of a very simple model as illustrated in Fig. 1. The forest itself is represented by a slightly conducting half space ($z < h$) which is bounded by an air half space (at $z > h$). Experimental results have confirmed[2] that this model is indeed adequate if the transmitting and receiving antennas are sufficiently high above ground. Hence, a ground plane (ordinarily located at $z = 0$) may be dispensed with; the average forest height h is then retained in Fig. 1 solely for quantitative comparisons with actual forests.

The propagation mechanism was shown[1] to consist of a lateral wave. This wave may be represented by a ray which starts at the transmitter T and is incident on the forest-air interface at the angle θ_c of total reflection, as shown at point A in Fig. 1. The wave then proceeds along the air-forest interface in the air region; it returns thereafter into the forest region along a direction given by the angle of total reflection θ_c, and finally reaches the receiver at point R.

To check the above wave mechanism under laboratory conditions, it is necessary to simulate the forest half-space. The proposed set-up for this purpose is indicated in Fig. 2. The forest medium is to be simulated by a lossy dielectric whose complex dielectric constant should be closely equal to that of the average dielectric constant of the vegetation. To circumvent the practical impossibility of the infinite extent of the forest and air half-spaces, the y dimension is rendered finite by using a parallel-plate structure, as shown in Fig. 2. This changes the three-dimensional aspect of Fig. 1 into a two-dimensional geometry without, however, affecting the essential wave mechanism. In the x and z directions, absorbers need to be placed so as to dissipate all incoming waves without reflection; in this fashion, the fields generated in the interior of the set-up will behave as if the geometry extended to infinity along x and z since no reflected fields will occur from the outer region.

The complete research program consists therefore in the design and construction of the above set-up as a first step. In a second stage, measurements will be taken in this set-up and these will be compared with those that were obtained in actual forest environments.

It was therefore decided to find a dielectric material whose permittivity and loss factor were in the ranges $1.01 < \varepsilon_1 < 1.5$ and $0.01 < \tan\delta < 0.1$, respectively. Unfortunately, such a specification could not be filled by commercially available materials since these are produced either as good absorbers ($\tan\delta > 1$) or as virtually lossless dielectrics ($\tan\delta < 10^{-3}$). It was therefore necessary to develop a suitable material whose properties would fit our requirements and it is pertinent to note that it was possible to achieve this aim by the end of the past period.

Preliminary investigations of commonly available materials, such as various kinds of wood and poor insulators, showed that none of them had a permittivity smaller than 2 - 2.5. It was therefore necessary to use rigid plastic foams which are available with permittivities in the range 1.02 - 2.0. However, their conductivity is much lower than that required, since their loss factor is smaller than 10^{-2}. It was decided to use a plastic foam that may be manufactured in the laboratory and add to it some absorbing materials during the foaming process in such proportions that the required loss factor is realized.

Experiments were thus carried out with several kinds of foam materials. In particular, the material designated as Eccofoam and manufactured by Emerson and Cumming, Inc., Canton, Massachusetts, was found to be more suitable than others. Extensive trials were made with three types (FPH, EFF10 and SIL) of this Eccofoam which were doped with a large variety of lossy powders such as graphite, cocoanut charcoal, animal charcoal, anode battery carbon, absorbent fibers, etc. All of these experiments have shown that the addition of lossy materials increases the foam permittivity considerably. Thus, for a foam which possesses values of $\varepsilon_1 = 1.08$ and $\tan\delta = 0.004$ without any doping, a value of $\varepsilon_1 = 1.42$ is reached if sufficient graphite is added so as to achieve a loss factor of $\tan\delta = 0.023$.

In view of the above behavior, a compromise was reached by using Eccofoam EFF10 with graphite (grit size between 250 and 420 μ) doping. This produces a material with $\varepsilon_1 = 1.5$ and $\tan\delta = 0.04$ and may be manufactured in sheets that are suitable for use in the parallel-plate set-up shown in Fig. 2. The uniformity of this material seems to be excellent and its only disadvantage is that its permittivity is somewhat high as compared to that of an average forest whose permittivity is more nearly equal to $\varepsilon_1 = 1.1$.

To circumvent the above disadvantage, a second material was developed which consists of Eccofoam FPH doped with absorbent fibers. This produces a material with $\varepsilon_1 \simeq 1.2$ and $\tan\delta \simeq 0.03$. However, the manufacture of sheets from this second material is difficult and results in a somewhat non-uniform product. These disadvantages will nevertheless be helpful in assessing the wave behavior in models of forest

whose vegetation is not sufficiently uniform. Hence, the second material will be suitable for use at a later stage, after the first material (EFF10 and graphite) is utilized to obtain meaningful results.

4. Preliminary Design of Experimental Set-Up

In addition to developing the dielectric materials described above, some effort was devoted to obtaining design specifications for the mechanical set-up and its associated measurement apparatus and a first set of rough sketches were drawn. These provide for probing of the field along directions parallel to the x axis shown in Fig. 2. The probing will be done continuously along most of the length of the air-dielectric interface and a similar continuous probing will be available along a vertical (z) direction. Additional features allow for placing the fixed (transmitting) antenna at any height with respect to the z axis.

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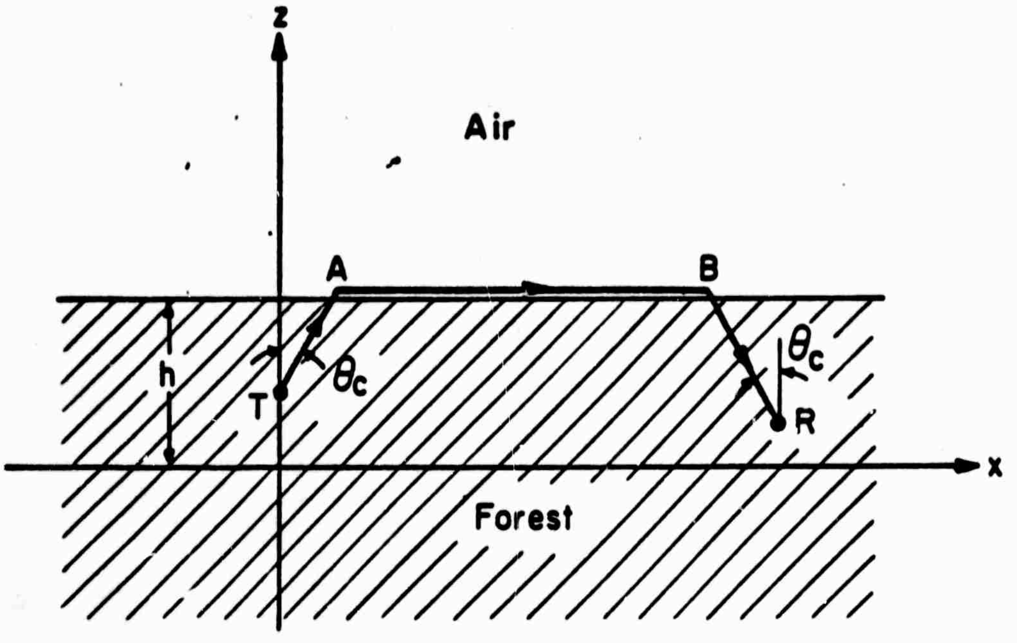

Fig. 1 Simplified model of forest.

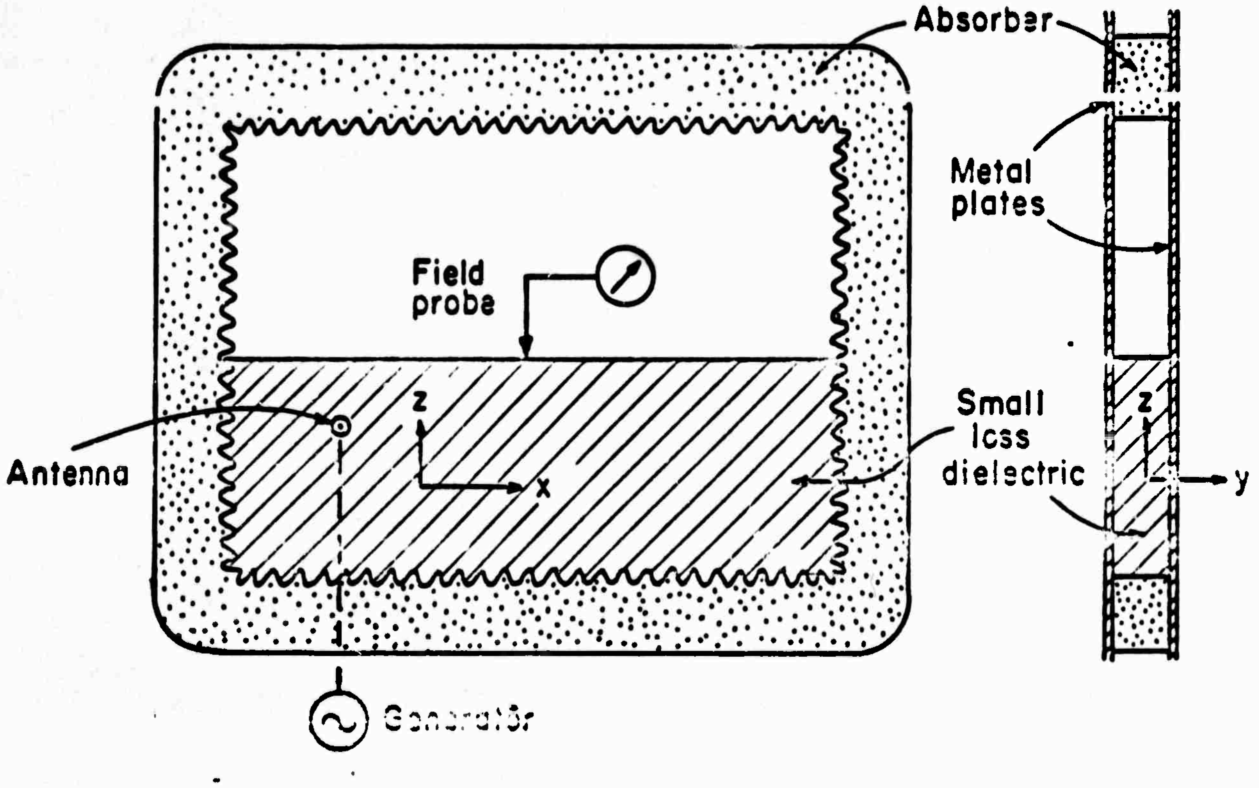

Fig. 2 Parallel-plate simulator

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Polytechnic Institute of Brooklyn, Electrophysics Department, 55 Johnson Street, Brooklyn, New York 11201	2a. REPORT SECURITY CLASSIFICATION 2b. GROUP Unclassified

3. REPORT TITLE

AN EXPERIMENTAL STUDY OF RADIO WAVE PROPAGATION IN SIMULATED FORESTS AND OTHER DISSIPATIVE ENVIRONMENTS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Semiannual Report No. 1, 15 February - 15 August 1968

5. AUTHOR(S) (First name, middle initial, last name)

TAMIR, Theodor

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1968	13	4

8a. CONTRACT OR GRANT NO. DAAB 07-68-C-0222 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) PIBEP-68-018.1 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) ECOM-0222-1

10. DISTRIBUTION STATEMENT

1. Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Advanced Research Projects Agency Washington, D. C.

13. ABSTRACT

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DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
laboratory simulation of forests						
wave propagation in simulated forests						